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"A Cloud Chamber Study of Positive
Particles from UX_2

by

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University of Alberta, 1948



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Introduction

In 1933 Anderson (1) discovered the existence of the positron in cosmic radiation by means of cloud chamber experiments. Soon after several investigators (2), (3), (4), (5), (6), (7), (8), (9), (10), (11), (12), (13) found that ^{positive particles} positrons are emitted by β -ray sources. The β -ray sources investigated were Th(B,C,C"), Ra(B,C), UX, P³², RaE, AcC". They found that about one in one hundred particles emitted are positrons. These positrons observed in a cloud chamber give rise to tracks with positive curvature and are not otherwise distinguishable from the electron tracks.

The interpretation of these tracks is difficult and presents contradictions between theory and results. The tracks could be negative tracks coming toward the source but in our case this is ruled out as a lead barrier was used. Investigators (4), (8), and (9), observed positive tracks in a cloud chamber even when the source was surround^{ed} by an absorbing material which should absorb all the positrons emitted from the source. These investigators (4), (8) and (9) concluded that these positrons were produced in the absorber. This assumption can be made on the basis of Dirac's theory of pair production by electrons. Experimental results

show that, for this process, in opposition to theory, there is a cross section approximately proportional to the charge number Z and is of the order of $\frac{Z}{82} \times 10^{-22} \text{ cm}^2$ ^{(3), (4), (5), (8) and (12).} (10^{-22} cm^2 for Pb). Theoretically this problem has been treated by (14), (15), (16) and 17 and the cross section was found to be proportional to Z^2 .

According to theory (18), (19) γ -rays from a radioactive nucleus should occasionally be "internally converted" by the production of a pair near a nucleus. The number of positrons thus excited by γ -rays should be about 2×10^{-4} per disintegration ^{(8) and (11).}. Ux_2 emits only weak γ -rays due to inner Bremsstrahlung. Also the emission of electrons from Ux_2 is not connected with a strong nuclear γ -radiation. Therefore for Ux_2 we can discount the possible production of positrons due to γ -ray conversion. The possibility of a radioactive element in the glass surrounding the source due to α -ray bombardment is also excluded.

Aliehanow (5) suggested that part of the positron spectrum must be ascribed to internal β -conversion. Sizoo and Barendse (9) conclude that the probability for this process is the same as for γ -ray conversion. This is in serious disagreement with the theoretical



results of Arley and Moller (20) who found the internal β -conversion coefficient to be 10^{-3} to 10^{-4} .

Therefore the rate of occurrence of positrons near β -ray emitters which was experimentally found to be of the order of 10^{-2} per decay electron is far too great to be accounted for by pair production due to internal and γ -conversion.

The apparent penetrating power and the absence of annihilation radiation which should occur if the particles are positrons led Bradt, Heine and Scherrer (13) to believe that the particles have a mass considerably less than that of the electron. The fact that the positive particles seem to lose momentum at a consistently higher rate than electrons of the same momentum and the lack of annihilation radiation led Smith and Groetzinger (21) to believe that they may not be positrons but have a higher mass.

The energy distribution of the positrons as found by investigators (8), (9) and (13) shows that by far the greater part of them have energies less than 300K.e.v.

This thesis is primarily concerned with a determination of the number and energy distribution of positive particles emitted per decay electron from UX and UX_2 and with the determination of the mass of these particles using the rate of change of momentum method (Appendix 3).



Plate 1. Cloud Chamber Proper

Apparatus

1. Cloud Chamber Proper

The cloud chamber (Plate 1) is of the type developed by Gilbert and Dee in the Cavendish Laboratory, Cambridge, England and was built in the National Research Council Shops at Chalk River. It is the diaphragm type and is expanded by an electrically operated valve system. The expansion is produced by opening a valve allowing the air to escape from the back chamber into a tank which is kept at a desired pressure by a system of pumps. The diaphragm moves downward causing an increase in the volume of the working chamber. The chamber operates satisfactorily in a cycle of three minor and one major expansion per 72 seconds.

The walls of the working chamber consist of a lucite cylinder with $\frac{1}{4}$ " wall thickness. Its main advantage is that it is less likely to shatter than glass and it contains no boron but if an alcohol-water mixture is admitted into the evacuated chamber it is likely to cause a large number of surface cracks on the inner surface. This may be attributed to the sudden cooling effect of the evaporating alcohol. The cylinder can be cleaned with Willson Plastic cleaner which also obliterates some small scratches. Aquadag rings $\frac{3}{8}$ " high were painted around the top and bottom of the inside surface to prevent light

5

scattering from the velveteen and the top plate.

Aquadag was used because it is a colloidal suspension of carbon and does not contaminate the chamber.

The bottom of the chamber is covered with black velveteen which is fairly loosely woven so as to allow air to pass through it freely. This provides a non-reflecting surface. The velveteen was sewn onto a brass hoop, made by bending 1/8" brass rod into a circle. This keeps the velveteen taut above the perforated plate and allows non turbulent flow of gas through it.

The electric clearing field of about 400 volts is applied between the brass bottom of the working chamber and an aquadag ring about 3/8" wide painted on the inside of the top plate. The aquadag ring is pointed out to the outside edge at two diametrically opposite points. Electrical contact is made with these points by means of insulated lead foil and one is used as one contact for the clearing field. The two together may be used with a voltmeter to check the presence of the field.

The diaphragm consists of natural rubber sheeting 1/32" thick obtained from the Ontario Rubber Co., Toronto, Ontario.

The joints between the units of the valve assembly and the evacuation tank are made gas tight by natural rubber gaskets 1/16" thick. The greasse cups on the expansion mechanism are packed with stop-cock greasse mixed with cotton batting as greasse itself tended to be sucked out during the evacuation process. This greassing process had to be repeated periodically. The joints between the cylinder and the top and bottom plates were made gas tight by natural rubber gaskets and if leaks persisted a bead of glyptal was run around the joints. The aluminium casting forming the base of the cloud chamber and the working chamber was found to leak and was painted with glyptal several times. This leak is not serious as it is isolated from the working chamber by the diaphragm and can be taken care of by the system of pumps on the evacuating tank.

In order to avoid disturbing the magnetic field distribution only non-magnetic materials were used in the chamber and the chamber stand.

A piece of lead pipe was wound around the base of the chamber and cold water passed through it. This cooling of the base prevents fogging of the cylinder and the top plate and keeps the thermal condition stable inside the chamber.

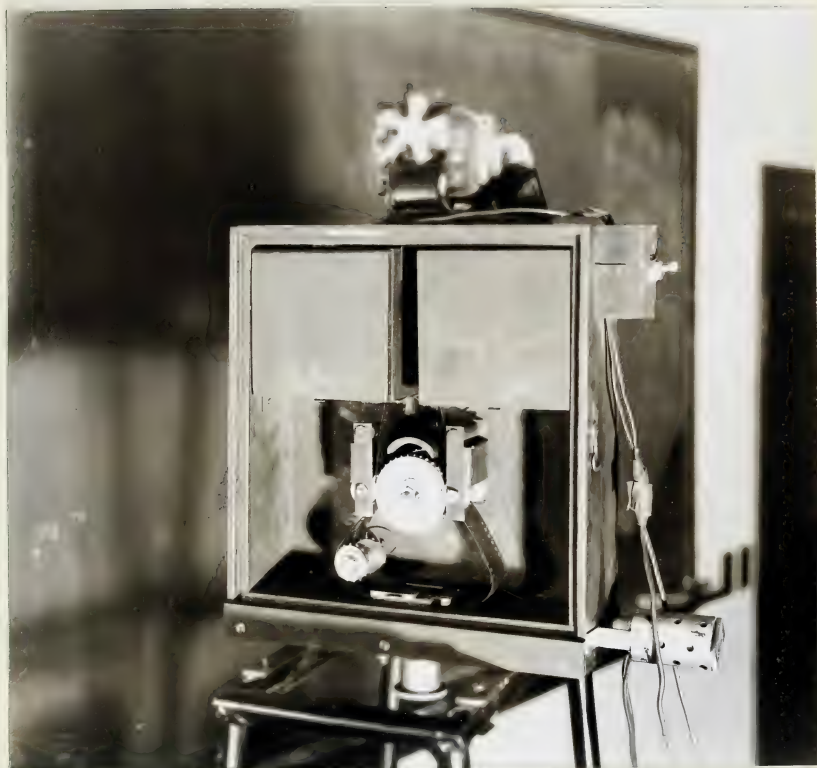


Plate 2. Camera



Plate 3. Cloud Chamber Completely Assembled.

2. Camera Arrangement.

The camera used (Plate 2) was designed and built in the Physics Department shop. It was fitted with a Leica Elmar F3.5 lens. The pull away shutter is operated by an electromagnet which is activated by relay/(Fig 1 and 2) which also switches on the Helmholtz coils. The shutter closes when the coils are switched off. For automatic operation a Flexo-action motor, 110 volts, 60 cycles, 10 r.p.m. made by Warkle Scuff Gear Co. is used to turn the film. The motor operates during the time the chamber is in the compressed position immediately after the major expansion. The drum, which turns the film, and the motor ^{are} ~~is~~ geared down by a system of pulleys so that the film is pulled through one frame during the time the motor operates. About twenty five feet of film can be placed in the camera at one time.

The camera is mounted on an aluminum stand which is bolted to the top Helmholtz coil (Plate 3). Stereoscopic photographs are obtained by using two front aluminized mirrors obtained from the Optics Section, National Research Council, Ottawa. The mirrors are mounted on the frame supporting the camera so that they are perpendicular to the top plate of the chamber and parallel to each other and $8\frac{1}{2}$ " apart. The bottoms of the mirrors touch the brass top of the chamber.



Plate 4. Lamp assembly

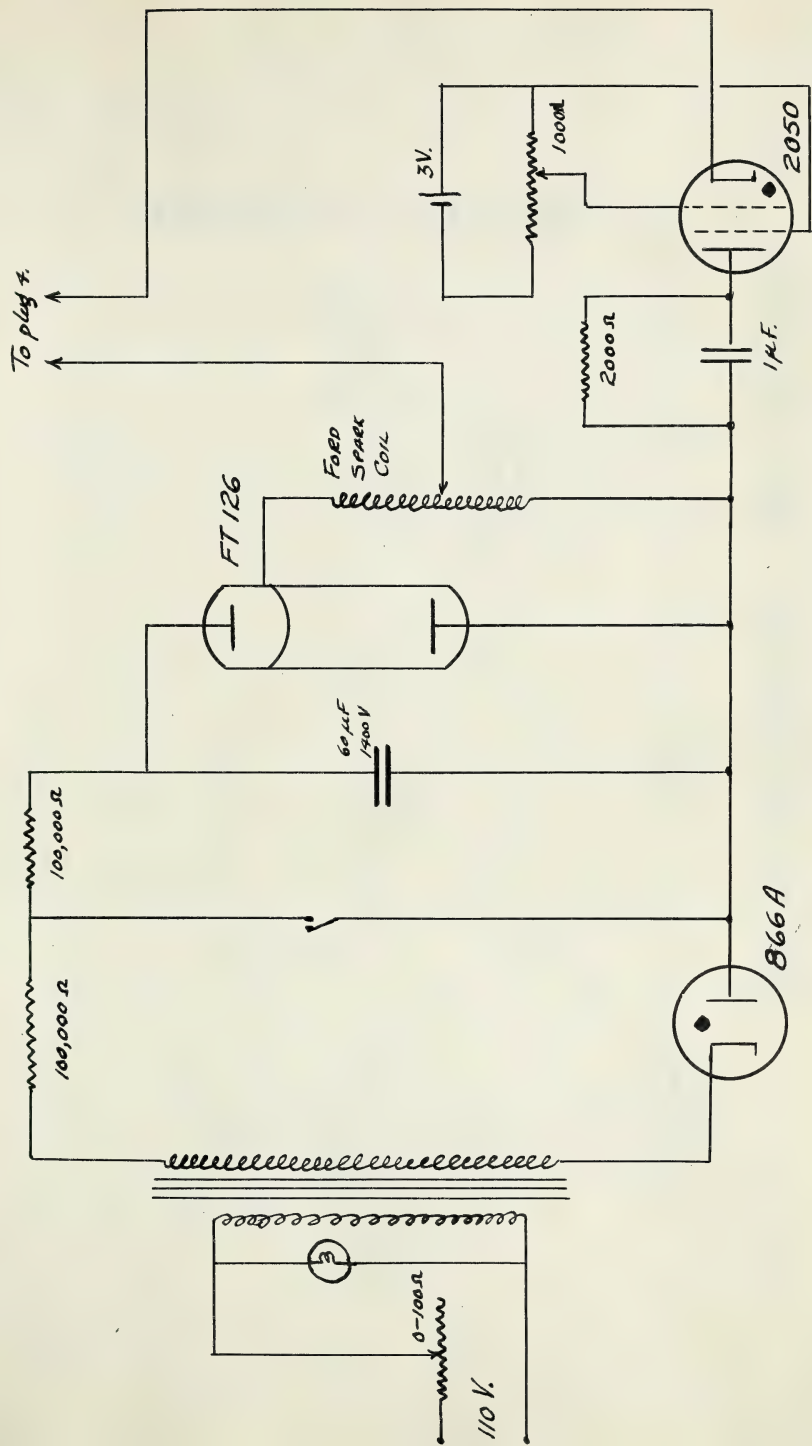


FIG. 3: FLASH CIRCUIT.

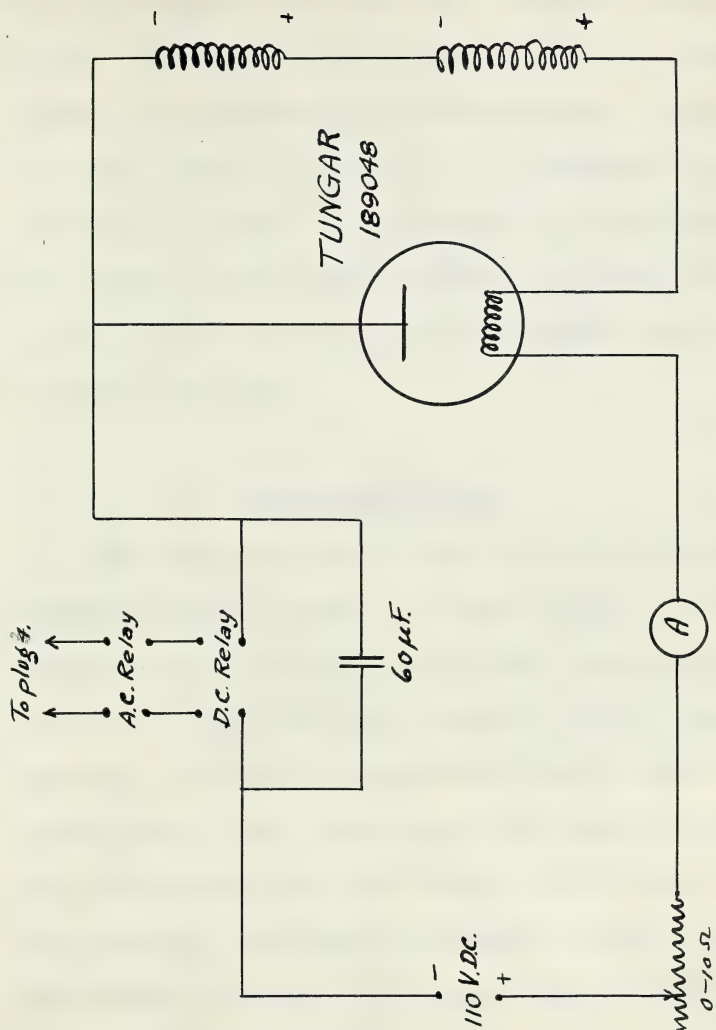


FIG. 4: HELMHOLTZ COIL CIRCUIT.

3. Illumination

The chamber is illuminated by means of a General Electric FT-26 lamp used in a circuit illustrated in fig 3. The back half of the lamp was silvered to increase the intensity of illumination. It was mounted in a box (Plate 4) so as to fit between the coils. The beam of light is collimated by a cylindrical lens made by splitting and polishing a 2" rod of lucite. A plane mirror is used on the side of the chamber opposite the lamp.

4. Helmholtz Coils

The Helmholtz coils were built in the National Research Council shops at Chalk River. The inside diameter of the coils is $12 \frac{1}{32}$ " and the outside $20 \frac{7}{16}$ ". The coils are spaced $7 \frac{15}{16}$ " apart by spacers. A layer of copper tubing is wound on the inner side of the brass spool for cooling purposes. The coils each have 1090 turns of #11 H.F. copper wire and are well insulated to stand a heavy current. The resistance of each coil is 5.8 ohms at 20°C . Using the simplified formula

$$B = \frac{0.9ni}{r}$$

where the symbols have the usual meanings, with the

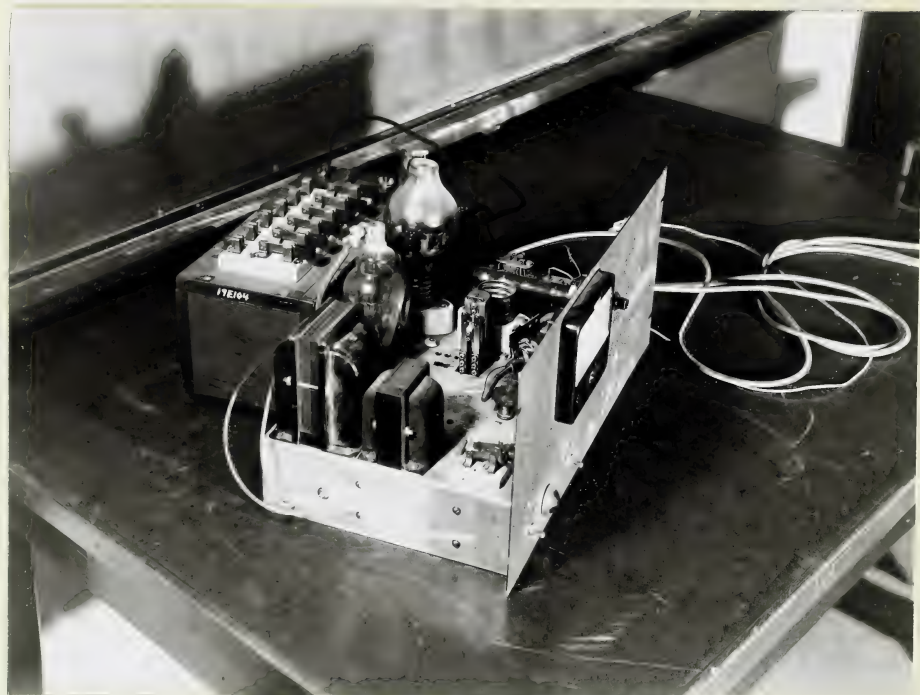


Plate 5. Flash circuit, helmholtz coil circuit
and automatic operation circuit.

coils in series and 110 volts across them, the field strength is found to be 500 gauss. The time for the field strength to reach a reasonably constant value was found to be about 1.8 sec,^{*} *because of inductance.*

The coils are connected in series and an arrangement as shown in Fig 4 is used to switch them on and off when carrying a current of 7.2 amps with 110 volts D. C. across them (Plate 5). Relay 1 switches 110 volts, 60 W to plug 3 which closes an A. C. relay which in turn closes a D. C. relay closing the Helmholtz coil circuit. To prevent arcing across the relay terminals on breaking the circuit a 60 pf condenser was connected across them.

For higher voltages and currents a Tungsar Mercury Vapor rectifier 189048 is connected in series with the coils as shown in Fig 4. When the circuit is broken the back e.m.f. of the coils is effectively short circuited by the rectifier, thus preventing arcing.

^{*}Pender and Mollwain, Electrical Eng. Handbook pp



Plate 6. Main Control Circuit

5. Control Circuits

(a) Main control circuit

The main control circuit was arranged as in Figures 1 and 2 and Plate 6. The purpose of the circuit is to carry out minor expansions. To do this a timing circuit is required using 2050 thyatrons. The grid^{condenser} charges up ~~through a condenser~~ to +400 volts until the tube E fires and relay 6 in the plate circuit closes. The closing of this relay starts the next grid condenser charging and tube F fires and closes relay 7 in the plate circuit. The process may be repeated endlessly. The time delays may be adjusted by varying selector switches Q and R.

For a main expansion plug 2(b) has to be closed and also switch S₂ which turns on the lighting circuit. When this is done relay 1 switches on the Helmholtz coils and also opens the shutter. After an adjustable time delay of from 0 to 7 seconds controlled by selector switch M, which gives the magnetic field time to reach a steady value, the chamber expands, relay 5 closes and relay 2 also closes switching off the electric clearing field.

At a time varying from 0.05 to 0.5 sec. controlled by selector switch S after relay 2 closes, the lighting

circuit is closed by relay 4. Relay 5 then opens the lighting circuit, turns off the magnetic field and turns on the electric field. The circuit then sets itself ready to repeat this cycle if plug 2(b) is closed or to carry out minor expansions if plug 2(a) (switch S₅) is closed.

The camera motor is run from plug 6 for the time that the chamber remains in the compressed position immediately after the main expansion.

All the condensers in the circuit are paper. The relays are made by Clare and Co. and are type A21316 with 18000 turns and a resistance of 2500 ohms. They are 6 terminal relays plus the coil terminals. 1 and 2, and 4 and 5 are normally closed, 3 and 3, and 5 and 6 are normally open. The positions reverse when the relay closes.

The following is a summary of the functions of the various parts of the control circuit:

Relay 1 - Switches 110V, 60W to Plug 3.

Relay 2 - Switches D.C. to Plug 1.

Relay 3 - Switches 110V, 60W to Plug 5.

Relay 4 - Switches 110V, 60W to Plug 4.

Relay 5 - Cuts off power to Plugs 3, 4 and 5.

Relay 6 - Closes relay 2 which causes compression.

Relay 7 - Opens relay 2 which causes expansion

Plug 1 - To expansion valves and clearing field

Plug 2 - To step switch -2(a) causes minor expansion
-2(b) causes major expansion

Plug 3 - To relay for Helmholtz coils.

Plug 4 - To lighting circuit.

Plug 5 - To relay for source.

Plug 6 - To camera motor

Plug 7 - To 110V, 60W msins

Plug 8 - Counter control

S₁ - Turns power on and off.

S₂ - Turns lighting circuit and source on and off.

S₃ - Turns on slow and fast expansion

Selector switch M - Controls time delay for
Helmholtz coils.

Selector Switch N - Controls time delay for source.

Selector switch O - Controls duration of flash
(This is not used with the present set up; condenser
discharge used).

Selector switch Q - Controls time in expanded
position.

Selector switch R - Controls time in compressed
position.

Potentiometer P - Controls electric field.

Potentiometer S - Controls flash delay.

(b) Automatic Operation

To make the circuit completely automatic a selector switch is used. The selector^{switch} is connected to a wheel, with twelve teeth, by a direct shaft. When the chamber compresses a ~~cannon~~^{solenoid} is energized by plug 2 pulling this wheel around and moving the selector switch through one step.

The complete cycle of operations consists of six cycles of the timing circuit. Three of these produce minor or clearing expansions, two leave the chamber in the compressed position to allow time for thermal equilibrium to be reached and the last one produces the major expansion.

(c) Minor Expansions

To produce minor expansions with this type of cloud chamber there are two alternatives (a) To make an expansion slow so that it is not adiabatic (b) to expand the chamber before it is fully compressed thus obtaining a small expansion ratio. Alternative (b) is used. Since the clearing expansions can be made rapid by adjusting Q and R the expansion can be made to take place before the pressure below the diaphragm



Plate 7. Repjection Arrangement.



has risen sufficiently to compress the chamber fully. The timing circuit was adjusted so that the chamber remains in the compressed position for 9.5 seconds which is not long enough to compress it fully. The time it remains in the expanded position is 2.5 seconds. The timing circuit is accurate enough to give consistent results. Three minor expansions are sufficient to clear the chamber. The chamber is allowed to stand for 24 seconds which is sufficient to bring it back to temperature equilibrium. With the timing circuit thus adjusted a major expansion occurs every 72 seconds.

6. Tilting Table

To measure the curvature of the tracks a tilting table was built consisting of a piece of bakelite, 12" x 12", painted white screwed on to an iron hemisphere (Plate 7). The ball fits onto the top of an iron cylinder with an electromagnet in the centre making contact with the ball. When an electric current is passed through the coil of the electromagnet the ball, cylinder and core of the electromagnet form a magnetic circuit without appreciable air gap. In this way the bakelite board is clamped tightly in position. A point on the board has four

degrees of freedom. Now if the camera and stand are placed above the tilting table, the film replaced in the camera, and the table adjusted, so that the two images of a track are reprojected back in the object plane, and then clamped, the curvature can be measured by determining the length and depth of a chord. This is done by means of a rule embedded in the table to measure the length of chord and a micrometer screwed onto the table to measure the depth of chord. Since only a small "slice" of the chamber is illuminated attention is paid only to tracks which lie almost in a plane perpendicular to the lines of force. Adjusting the intensity of the source so that a reasonable number of tracks appear in the slice simplifies the measurement of the radii of curvature of these tracks.

Since the same camera is used and the film and mirrors are in the same relative position which they occupied when the exposure was made many errors which might arise because of bad alignments of the camera and mirrors are eliminated.

Experimental Procedure

Conditions for best tracks are obtained with a minimum expansion ratio of 1.125. This is possible if a mixture of 65% ethyl alcohol and 35% water is used with air in the cloud chamber (22). Better results may be obtained if a mixture of 2:1:1 of ethyl alcohol, water and acetone is used as the acetone increases the contrast between the tracks and the background fog but this is impossible in our case as acetone would attack the lucite cylinder.

About 5 cc of this alcohol-water mixture was put in the chamber. Air at atmospheric pressure was used as the gas.

A UX_1 source was prepared according to the method of Hahn (Appendix 1). The precipitate was dissolved in nitric acid and a drop of it evaporated in a glass tube 2 mm in diameter, 2.5 cm long and a wall thickness of 60 microns. The tube was sealed at both ends and fastened to a brass bracket fixed to the inside wall of the lucite cylinder.

144 photographs were taken using Ortho Recording negative film. The film was developed in D-19 for 7 minutes washed and fixed.

A piece of lead foil 0.004 cm thick (43.5 mgm./cm²)

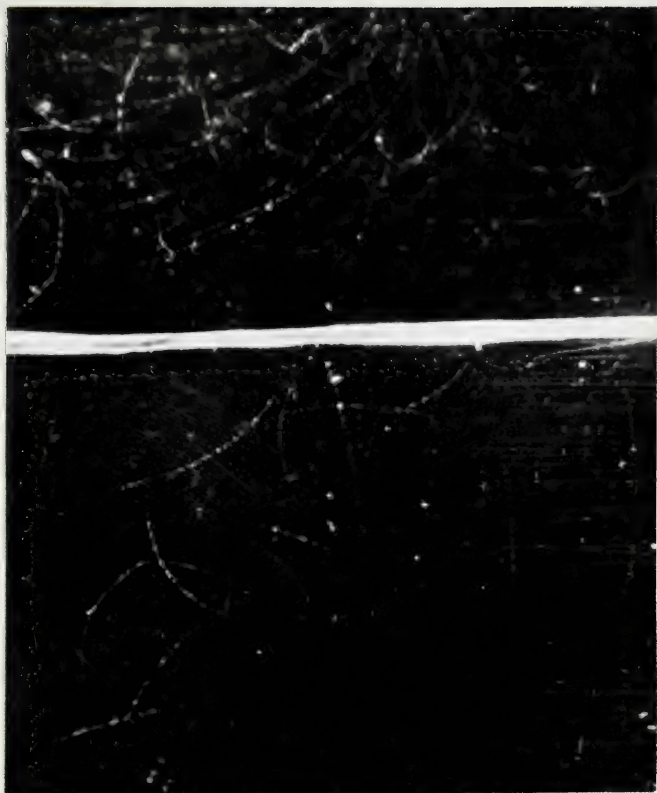


PLATE 9.

Pair Production Due to External Conversion

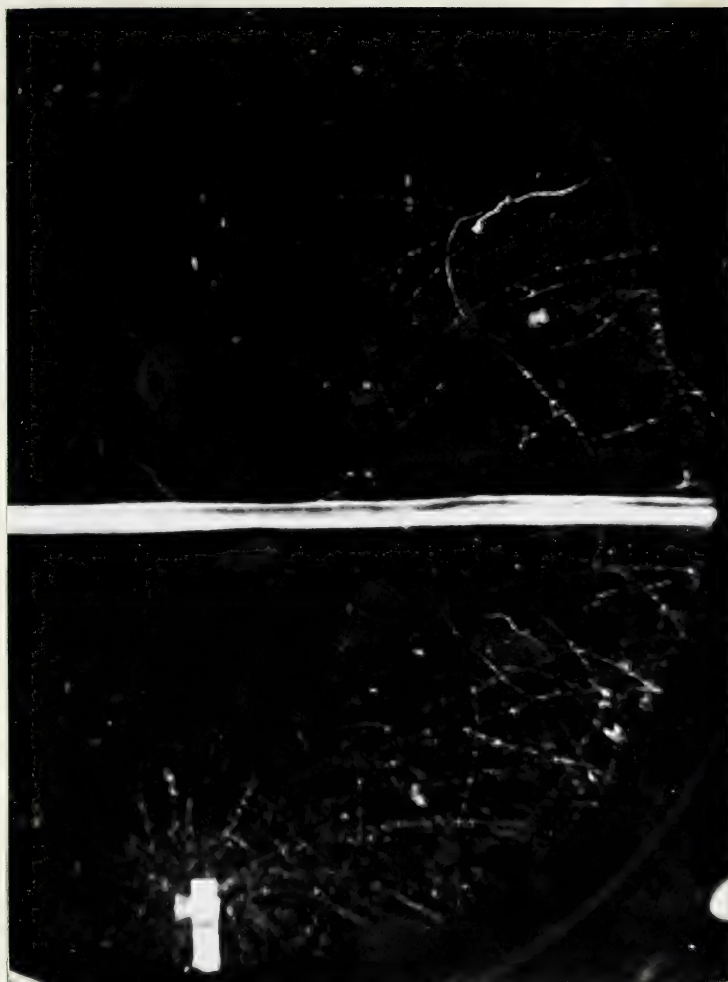


PLATE 10

Pair Production Due to Internal Conversion

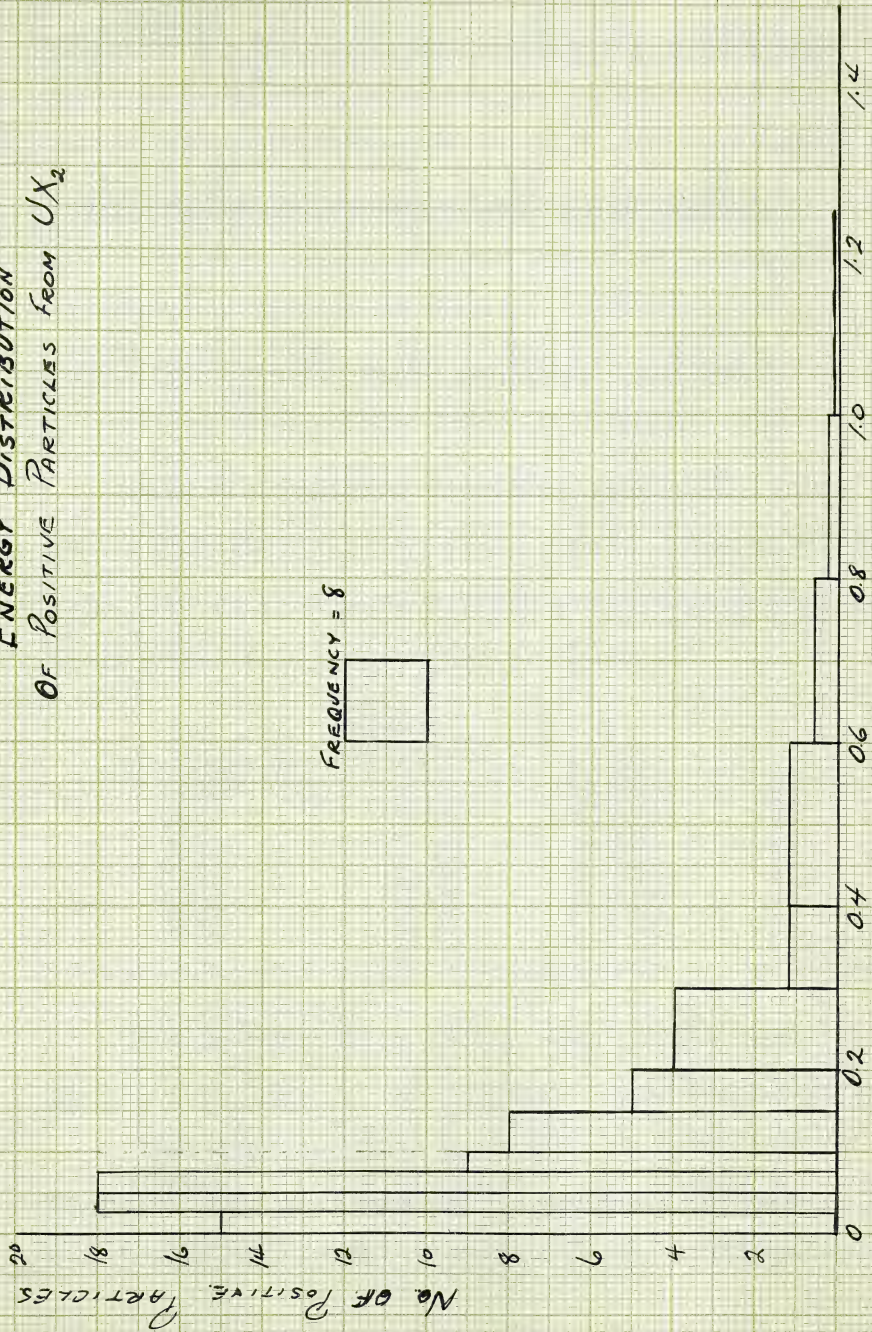
was placed across the chamber perpendicular to the flash tube. 212 photographs were taken with the foil 7.5 cm from the source and 286 photographs with the foil 5.0 cm away.

The current in the Helmholtz coil circuit was maintained at 7.20 amps which gave a field of 350 gauss. The reason for using a low field is to reduce multiple scattering of low energy particles.

Results and Conclusions.

Without the lead foil in the chamber 2161 electron tracks and 23 with positive curvature ~~±~~ were observed giving a ratio of one positive particle for every 94 electrons emitted. With the lead foil across the chamber 10,415 electron tracks and 103 positive ones (Plate 10) were observed giving a ratio of 1 in 102. A total of 12,576 electron tracks and 126 positive tracks were observed for a ratio of 1 in 101 which agrees well with other workers (8) and (10). The energy distribution of the positive particles is given in table 1, and fig 5, and was calculated from the determined values of $H\rho$.

ENERGY DISTRIBUTION OF POSITIVE PARTICLES FROM UX_2



ENERGY IN Mev.

FIG. 5.

Table 1

No. of positive particles	15	18	18
Energy in m.e.v.	0-0.025	0.025-0.050	0.050-0.075

10	16	10	20
0.075-0.100	0.100-0.150	0.150-0.200	0.200-0.400

11	5	2	1
0.400-0.600	0.600-0.800	0.800-1.00	1.00-1.25

Only six positive particles were observed to go through the foil and their masses were estimated using the rate of change of momentum method (appendix 3). These results are contained in Table 2.

Table 2

Hp gauss-cm	$\frac{d(p)}{dx} \times 10^5$ gauss-cm.	$\frac{\beta}{\sqrt{1-\beta^2}}$	M/m.
2850	5.36	0.374	4
3340	7.00	0.333	6
1440	1.28	0.757	1
1440	1.35	0.733	2
3325	2.71	0.500	4
1890	0.80	1.000	1

The average ratio of the mass of the positive particle to that of the electron is of the order of 3.

With the lead foil 5 cm away from the source
(P. 4e 9)
74 pairs were observed due to external conversion in the lead foil. This gives a ratio of 1.15 positive

particles per 100 electrons. With the lead foil 7.5 cm away from the source 36 pairs were observed giving an incidence of 0.88 per 100 electrons.

These results afford a new confirmation of the unexpectedly high values of the probability for the internal and external production of pairs by β -particles. The results are in good agreement with Da Silva (8) and Sizoo and Barendregt (10). The source was not surrounded with lead as was the case with investigators (8) and (10) so that pair production is entirely due to external conversion and not to positrons penetrating the foil. Eighty-six percent of the positrons have energies less than 0.4 m.e.v.

The difference in the numbers of pairs produced with the two different positions of the lead foil may be due to the loss of energy by the β -particle due to ionization. For values of H_p from 1000 to 6000 gauss on the corresponding number of ion pairs produced per cm in air varies from 200 to 45. The energy spent in the production of an ion pair is about 32 e.v. Therefore the energy loss for 2.5 cm varies from 3,900 e.v. to 17,500 e.v.* Since the kinetic energy of the pairs is $E - 2m_0c^2$, where E is the energy of the incidence β -particle, the loss of energy due ionization reduces this value and results in a smaller number of

* Rasetti, F. - *Elements of Nuclear Physics*.

pairs produced.

The mass of some of the positive particles was found to be greater than that of the electron although the number of positive particles traversing the lead foil was too small to give a good statistical value for the mass. The masses of the particles are significantly different from that of the electron. Whether they all have the same mass is not definite without further investigation. It is interesting to note that the higher energy particles whose tracks would be less distorted by scattering are found to have a greater mass. This is in disagreement with Bratt, Heine and Scherrer (12) who concluded that the mass of the positive particle is considerably less than that of the electron but is in agreement with Smith and Ureetzinger (21) who suggested it is higher.

Acknowledgements

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I am indebted to Dr. Harris of the Chemistry department for his advice and assistance in the preparation of a UX₂ source; to Mr. K. L. Erdman for his assistance with some of the work; to the Electrical Engineering Department for their interest and trouble in making available a steady D. C. supply.

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Appendix 1Preparation of UX_1 Source *

A considerable amount of uranium nitrate was dissolved in ether. The hexahydrate water forms an aqueous layer. After vigorous agitation the uranium nitrate will remain in the ether while the UX_1 with some uranium will be in the aqueous layer. This aqueous layer is milked off and a few milligrams of ferric nitrate are added to it. Ammonia is then added to precipitate the uranium and iron. To re-dissolve the uranium, concentrated ammonium carbonate is added and the solution warmed. The iron hydroxide which carries the UX_1 is then filtered out and dissolved in a little nitric acid. A drop of this solution is evaporated in a thin walled glass tube which is sealed off to make the source.

The uranium can be recovered and the process repeated after 25 days, the half life of UX_1 .

* Hahn, O. - *Applied Radiochemistry* pp 33-35

Appendix 2

Calibration of Field Inside Helmholtz Coils

The uniformity of the field inside the Helmholtz coils was checked using a flip coil method. The coil (Plate 8) was laid horizontally in the field with the flux HA_n passing through it. The coil was then turned through 180° about a horizontal axis. The flux through the coil is reversed so that the change in flux is $2HA_n$. The charge q sent through a wall type galvanometer is

$$q = \frac{2HA_n}{10^9 (R+G)} \dots\dots\dots (1)$$

and

$$H = \frac{q \times 10^9 (R+G)}{2An} \text{ gauss} \dots\dots\dots (2)$$

where R is the resistance of flip coils and leads, G the resistance of the galvanometer, A the area of the flip coil and n the number of turns.

Accurate setting of the coil and rotation through exactly 180° is not necessary. If the plane of the coil makes an angle θ with the lines of force, the flux through the coil is given by

$$N = HA_n \sin \theta$$

and differentiating

$$\frac{dN}{d\theta} = HA_n \cos \theta$$

$$\text{Then } \frac{dN}{N} = \cot \theta d\theta \dots\dots\dots (3)$$

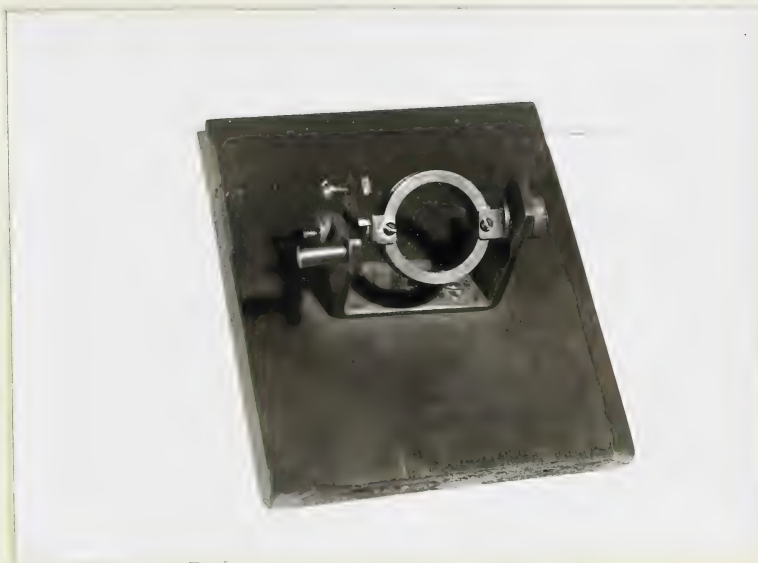


Plate 8. Flip Coil.

Since $\cot \theta$ is very small with θ in the neighborhood of $\pm 90^\circ$ the error involved because of a small error in angle $d\theta$ is thus very small, *less than 0.1 %*.

The flip coil (Plate 8) has 47 turns and a mean diameter of $3.40 \pm .005$ cm. and an area of $9.08 \pm .03$ cm². The resistance of the galvanometer and coil was found to be $1112 \pm .5$ ohms by a bridge method. The galvanometer was calibrated using a condenser discharge method and the sensitivity was found to be 0.0050 ± 0.00005 */a coul. per mm.*

Galvanometer deflections were obtained for the following points in a plane halfway between the coils taking the centre of the coils as the origin and using a $7.2 \pm .05$ amp. current.

Coordinates of point	0,0	0,5	0,11.2	5,5	9,9	5,0	9,0	11,0
Galvanometer deflection	9.03	9.05	8.73	9.02	8.06	9.09	8.97	8.40

-5,5	-8.7,9.8	5,0	-9.4,0	-5,-5	-9,-9	0,-5	0,-11
9.10	8.22	9.08	9.02	9.07	8.43	9.03	9.05

5,-5 9,-9
9.03 8.54

The above readings are ^{each} an average of six taken.

The field is uniform to within 0.5% over a region bounded by two horizontal planes one 2.5 cm above, the other 2.5 cm. below the midplane of the coils and a cylinder of 9 cm. radius measured from the axis of the coils.

Using the average galvanometer deflection $9.05 \pm .05$ obtained for a current of $7.2 \pm .05$ amps in equation (2) the field was found to be $350 \pm 2.5\%$ gauss. Using the Helmholtz formula the field was found to be $350 \pm 1.5\%$ gauss for the same conditions.

Appendix 3

Determination of Mass from the Rate of Change of Curvature *

The rate of change of momentum of a particle can be determined by inserting a plate inside the cloud chamber and measuring the curvature of a track on both sides of the plate.

A particle of mass M , charge z and momentum p moving at right angles to a magnetic field of H gauss describes a track with a radius of curvature ρ cm where

$$pc = \frac{H\beta c^2}{\sqrt{1-\beta^2}} = 300 \ z H \rho \dots\dots\dots(1)$$

where pc is in e.v. and $H\rho$ in gauss cm. Knowing $H\rho$ the momentum of the particle may be obtained directly provided z is known.

Differentiating (1) we get

$$\frac{d(H\rho)}{dx} = \frac{c}{300} \frac{dp}{dx} = \frac{1}{300\beta} \frac{dE}{dx}$$

if $z = 1$.

The average rate of dissipation of energy through ionization and excitation by a fast primary particle of mass M , velocity c and charge e in air is

* (Reference, Das Gupta and Ghosh (22)).

$$-\frac{dE}{dx} = \frac{2 \times 10^2}{\beta^2} \left[9.43 + \log \frac{\beta}{\sqrt{1-\beta^2}} - \beta^2 \right] \dots\dots\dots (2)$$

in e.v. per cm of air.

Then

$$\frac{d(Hp)}{dx} = \frac{1}{200\beta} \frac{dE}{dx} = k \left(\frac{\beta}{\sqrt{1-\beta^2}} \right) \dots\dots\dots (3)$$

The values of $\frac{d(Hp)}{dx}$ corresponding to a value of $\frac{\beta}{\sqrt{1-\beta^2}}$

can be calculated and are given in the table and graph.

From (1) with $z = 1$ we have

$$\frac{M}{m} = \frac{He\beta}{mc^2} / \frac{\beta}{\sqrt{1-\beta^2}} = \frac{Hp}{1704} / \frac{\beta}{\sqrt{1-\beta^2}} \dots\dots\dots (4)$$

where Hp is in gauss-cm and $\frac{M}{m}$ is the ratio of the mass

of the unknown particle to the mass of the electron.

Knowing $\frac{d(Hp)}{dx}$, $\beta / \sqrt{1-\beta^2}$ was found and substituted

in (4) to determine $\frac{M}{m}$. The results are given in table 3, and Fig 6.

Table 3

$\frac{\beta}{\sqrt{1-\beta^2}}$	.3	.4	.5	.6	.7	.8	.9
β	0.288	0.372	0.449	0.515	0.574	0.625	0.667
$\frac{d(Hp)}{dx}$ gauss-cm / cm lead	8.33×10^5	4.33	2.71	1.91	1.45	1.15	0.94

1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.8
0.706	0.739	0.768	0.793	0.814	0.832	0.848	0.874
0.80	0.72	0.67	0.62	0.56	0.545	0.543	0.542

RATE OF CHANGE OF MOMENTUM
AS A FUNCTION OF $\frac{\beta}{\sqrt{1-\beta^2}}$

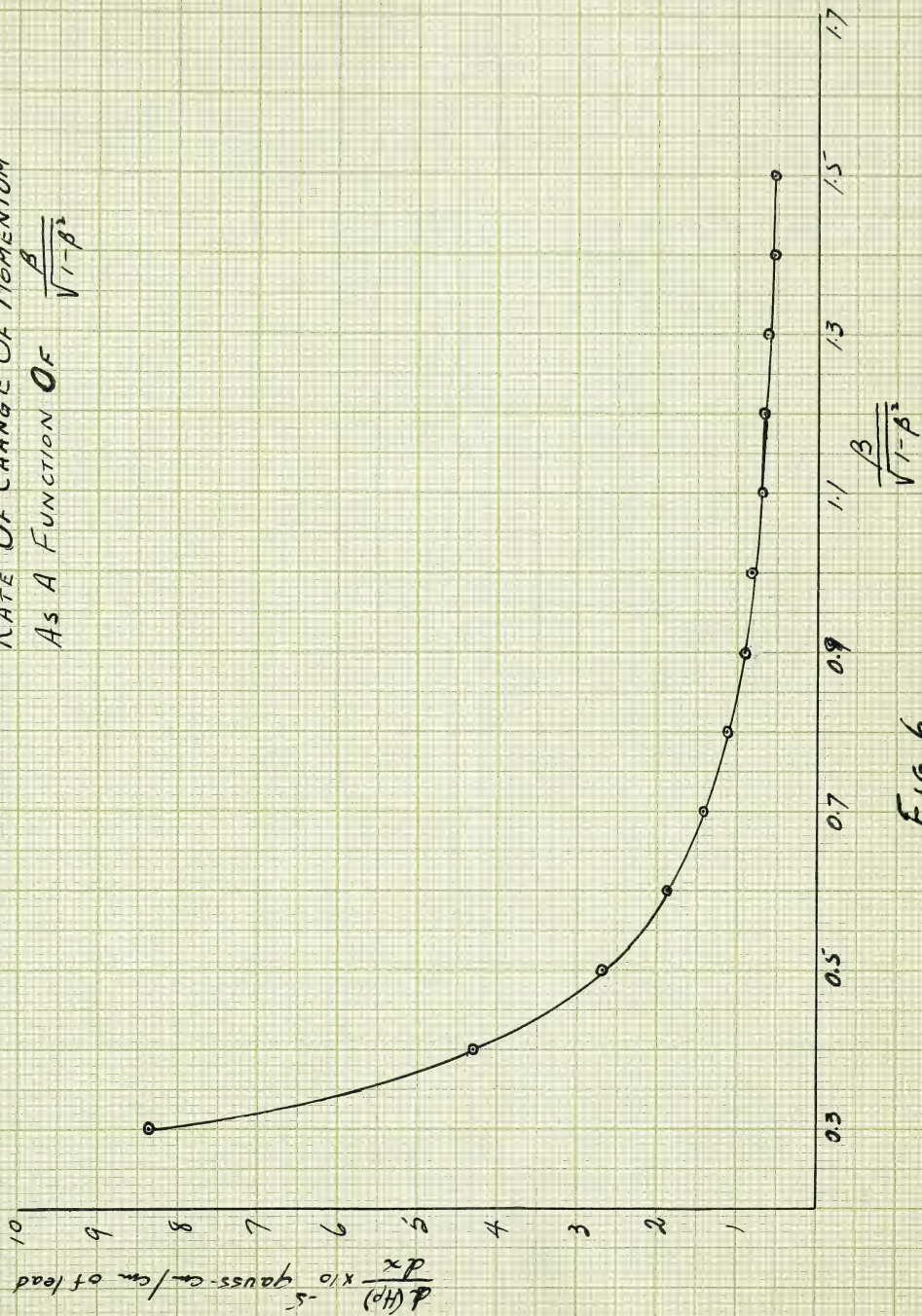
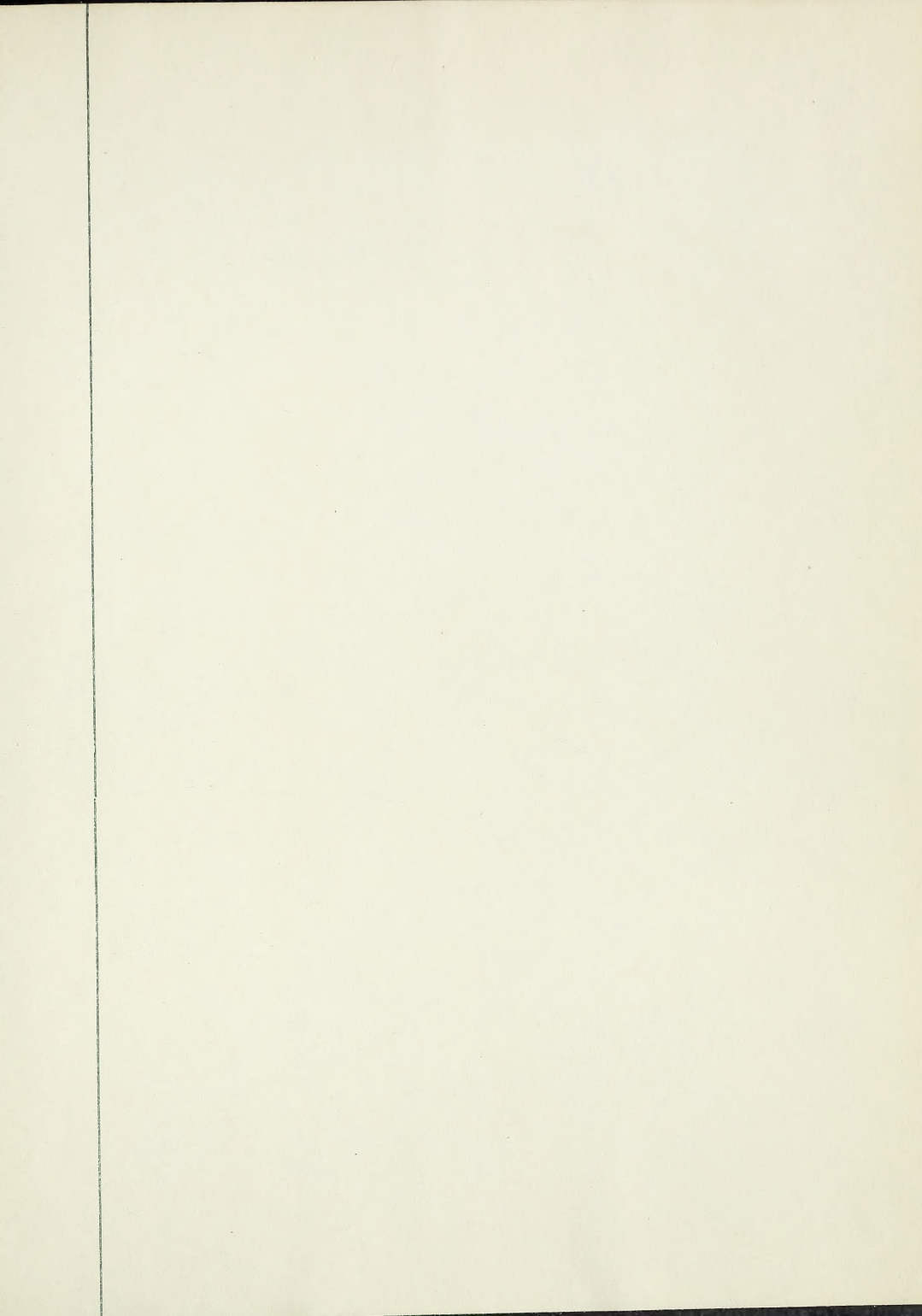


Fig. 6.





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